

# **Investigation of Complex Range-Dependent Shallow Water Sound Transmission**

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## **LONG-TERM GOALS**

This Postdoctoral Fellowship (Jon M. Collis) had three main goals. The first was to quantify the water sediment interaction zone boundary condition for acoustical applications, using theory, numerical computation, experimental results, and constrained inversions. The second was to use range-dependent codes along with geoacoustic profiles based on geophysical properties to develop hypotheses suitable for testing with at-sea experiments in waveguides with sandy bottoms. The third was the conduct experiments with a near bottom sound source and array to quantify the characteristics of the interface wave field.

## **OBJECTIVES**

In general with a sandy bottom that has depth-dependent sound speed, attenuation, density and porosity profiles, the measured modal attenuation coefficients, and consequently the attenuation of sound in the water waveguide, will have a nonlinear frequency dependence less than quadratic [1]. Numerical field calculations that use the range-depth dependencies of the bathymetry and the bottom should be capable of determining the correct intrinsic frequency dependence, when sufficient experimental sound transmission and environmental data are available.

Boston University investigators developed the low noise state-of-the-art towed array system towed behind a small autonomous vehicle [2]. Also, a simplification of Biot's sediment model was developed that predicts nonlinear ( $n = 2$ ) frequency dependent attenuations [3,4]. Results from the Nantucket Sound I experiment were found consistent with this simplified Biot theory for sandy-silty sediment bottoms [2].

The first objective was to quantify the water sediment interaction zone boundary conditions using theory, numerical computation, experimental results, and constrained inversions. Experimental sound transmission results from shallow-water experiments provided the experimental basis for our numerical studies to meet objectives.

The second objective was based on measurements of sound transmission from a source and array near the bottom, as well as state-of-the-art propagation codes and geoacoustic models, to quantify the properties of water/sediment interface waves.

In the near term, the Nantucket experiments were conducted with the source/receiver at the ocean-sediment interface. The sound transmission results were compared with range-dependent calculations that use geoacoustic profiles that incorporated the simplified Biot theory and elastic layers. Synthetic

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<b>14. ABSTRACT</b> <p><b>This Postdoctoral Fellowship (Jon M. Collis) had three main goals. The first was to quantify the water sediment interaction zone boundary condition for acoustical applications, using theory, numerical computation, experimental results, and constrained inversions. The second was to use range-dependent codes along with geoacoustic profiles based on geophysical properties to develop hypotheses suitable for testing with at-sea experiments in waveguides with sandy bottoms. The third was the conduct experiments with a near bottom sound source and array to quantify the characteristics of the interface wave field.</b></p>				
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aperture processing techniques were used to analyze the data to produce sound transmission results such as the horizontal wave number spectra.

## APPROACH

The technical approach can be summarized as employing a balance between theory, numerical computation, and measurement to resolve extent issues concerning the water sediment boundary condition. The approach will use the state-of-the-art simplified Biot theory [3,4] and the towed array system to measure phenomena near to the water/sediment interface. Numerical calculations were used to guide experiments, benchmark the measurements, coupled with constrained inversion to estimate geoacoustic profiles. Advanced signal processing algorithms were employed to determine the effects of range-dependent fluctuations on performance.

A typical experiment involved the towed-array-autonomous vehicle system and moored sound sources. The system varied depth over bottom for different experimental runs. The received pressure variations were recorded in a pod carrying data recorders. These data were merged with vehicle location data to yield the received pressure as a function of time and range. The data were processed with time frequency transforms and synthetic aperture techniques to yield the horizontal wave number spectrum to characterize interface phenomena (compressional, shear, and evanescent waves).

## WORK COMPLETED

The Postdoctoral project was initiated during July 2006. The Post Doctoral Investigator participated in both the SW06 and AWACS experiments. Initially between July and December 2006, prime activity for the Investigator was the acquisition and analysis of results from the SW06 experiment. During the first year of this grant, the Investigator worked in conjunction with WHOI and BU investigations to characterize range-dependent sound transmission in the complex SW06 environment. Research calculations were conducted to guide the analysis of measured results [5,6]. In addition to participating in the SW06 and AWACS field tests, three noise characterization experiments were performed in Buzzard's Bay and the Nantucket Sound II experiment, was conducted to measure the interface wave field near the water-sediment boundary interface. Supporting environmental measurements were made for each experiment, where data collected, in addition to acoustic measurements made with the towed hydrophone array system and the autonomous vehicle that included position, water depth, conductivity, and temperature.

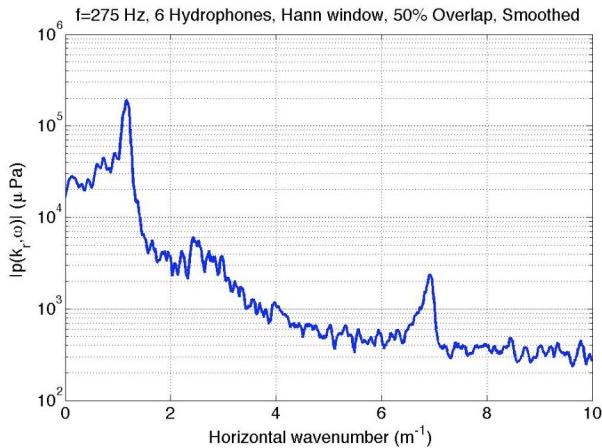
## RESULTS

Sediment attenuation has an important effect in many underwater acoustics problems, in particular those of shallow waters. Results have shown that the accurate calculation of the acoustic field in a shallow-water waveguide with sandy sediment bottom requires a nonlinear frequency-dependent compressional wave attenuation in the upper layer of sediment. Careful examination of experimental data, summarized in [1,2 and 8], show that the accurate calculation of shallow-water sound transmission between 100 Hz and 1 kHz in a waveguide with sandy-silty bottom requires a nonlinear frequency-dependent attenuation,  $n \approx 1.8 \pm 0.2$ , in the near-water sediment layer. However, the simplified theory of Biot predicts a quadratic (nonlinear) frequency dependence,  $n = 2$ . Though both

theory and experiment show nonlinear frequency dependence, there is a difference between theory and experiment.

A recent paper discusses calculations used to explain the less than quadratic frequency dependence of compressional wave attenuation [7,8]. To quantify the attenuation properties of shallow-water waveguides, various physical mechanisms were considered as possible influences on propagation. In particular, the influence of sound speed and attenuation gradients and effects due to elasticity were discussed. It was determined that effects due to shear can result in greater effective attenuation than is expected from a quadratic frequency exponent. For shear wave speeds of approximately 300 m/s, these effects are in general agreement with less than quadratic expected values. [8]

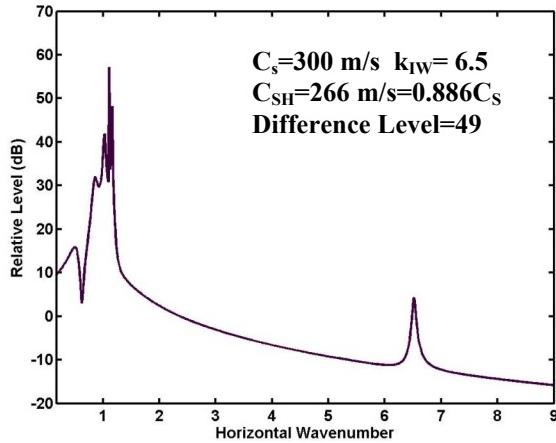
To better quantify the effects that shear has on shallow-water sound propagation, an experiment, Nantucket Sound II, was conducted during August of 2007. The experiment involved a bottom mounted source and a near-bottom array system towed behind a small autonomous vehicle. The goal of the experiment was to estimate water-sediment interface horizontal wave number spectra as shown in Fig. 1 (results reported last year and in [9]). The measured pressure  $P(r,t)$  was Fourier Transformed to yield  $P(r,\omega)$  and then a synthetic (Fourier-Bessel) Hankel transform was used to yield  $P(k,\omega)$ . Horizontal wavenumber estimates,  $P(k,\omega) \cdot P(k,\omega)^*$ , were found to show modal wavenumber peaks as well as an additional peak that is consistent with an interface wave. Figure 1 shows the pressure transform magnitude,  $|P(k,\omega)|$ , as a function of horizontal wavenumber,  $k$ . A spectral peak occurs at approximately  $k=6.95 \text{ m}^{-1}$  that implies a an interface wave speed of 249 m/s and a shear wave speed of approximately 284 m/s.



**Figure 1: Spectral magnitude versus horizontal wave number ( $k$ ), estimated from transmission measurements by use of the synthetic Fourier-Bessel (Hankel) transform. The spectral peak at  $k=6.95$  some 40 dB less than the water wave-number peak ( $k=1.1$ ) corresponds to an interface wave speed of approximately 249 m/s. (reported last year and in [9]).**

Calculations were performed with a fast field code to estimate the wave number spectra by first calculation of the complex pressure field versus depth and then performing the Hankel Transform

yielded the result shown in Figure 2. However there are some significant differences between the measured and calculated result. First the relative magnitude of the water borne and interface wave is on the order of 9 dB, second the shape of the peak is much different and third the structure preceding this spectral peak is important. Calculations of this spectral with realistic geoacoustic gradients show not only the interface wave but trapped shear waves produce several features prior to the interface wave peak. Processing issue could also be important and the coherent processing of the array is continuing. However despite the care taken in the performance of this experiment and the fact that the preliminary results are impressive, an additional experiment has been planned to eliminate experimental uncertainties and perform measurements at lower frequencies.



**Figure 2: The HWNS computed for the best fit geoacoustic model for the Nantucket Sound Experiment. The interface wave spectral peak is shown with a  $k=6.5$**

## IMPACT/APPLICATIONS

Numerical studies show that the observed less than quadratic frequency dependence can be explained by shear wave leakage and subsequently accounted for in standard underwater acoustic propagation models. The horizontal wavenumber measurement technique represents a new method for shear wave speed measurement in shallow water.

## RELATED PROJECTS

Initially the Postdoctoral work was under the ONR Multiphase Media Investigation at Boston University. This current effort is currently completed but was directly related to the Multiphase Media Investigation. The ONR Postdoctoral Grant to Boston University had Professors William Carey and Allan Pierce as advisors.

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